

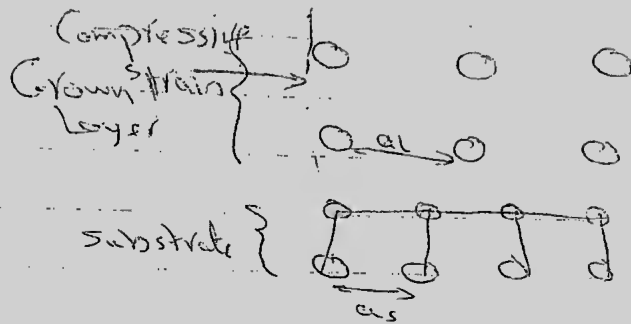
11/12 السبت III

Date: _____

"Strained Layer Epitaxy"

compressive strain:

atoms of grown layer adjust
themselves to be matched
atoms of substrate



Condition: $d(\text{thickness of grown layer}) < d_c$

$$d_c = \frac{a_s}{2|\epsilon|}, \quad \epsilon = \frac{a_L - a_s}{a_L}$$

mismatch parameter

$$\epsilon = 0.01, \quad a_s = 5 \text{ \AA}^0$$

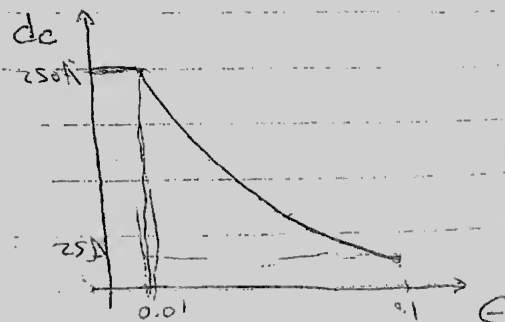
$$d_c = \frac{a_s}{2|\epsilon|} = \frac{5}{2 \times 0.01} = 250 \text{ \AA}^0$$

$$\epsilon = 0.1, \quad a_s = 5 \text{ \AA}^0 \rightarrow a_L = \frac{5}{0.9} \text{ \AA}^0$$

$$d_c = \frac{5}{2 \times 0.1} = 25 \text{ \AA}^0$$

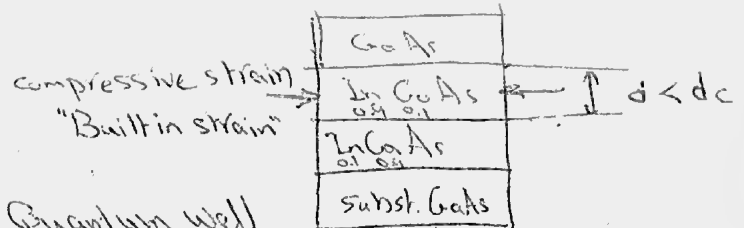
In GaAs/GaAs
 $x \times 1-x$
 $\text{GaAs} \rightarrow a = 5.65 \text{ \AA}^0$

In $\text{As} \rightarrow a = 5.87 \text{ \AA}^0$



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It will be strained Quantum well Structure

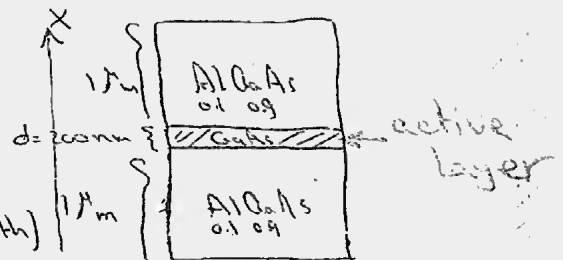
As the Thickness must be very small

Double Hetero Structure: (Quantum well structure)

two semiconductor materials grown into a sandwich

type I: outer layers → material has E_{g1} ,
 & the sandwiched layer has $E_{g2} < E_{g1}$
 ex: $\text{AlGaAs} / \text{GaAs}$
 $x = 1-x$

→ Thickness $d < \lambda$ (de Broglie wavelength)



$$\lambda = \frac{2\pi\hbar}{P}$$

$$P = \frac{h}{\lambda} = \frac{\hbar k}{\lambda} = \sqrt{2m^* E_{KE}}$$

$$E_{KE} = \frac{1}{2} m v^2$$

$$= \frac{p^2}{2m}$$

$$P = \sqrt{2m^* E_{KE}}$$

$E_{KE} = \text{thermal energy}$
 $T = 300K$

$$E_{KE} = 0.025 \text{ eV}$$

$$m_0^* = 0.067 m_0 = 0.067 \times 9.1 \times 10^{-31}$$

$$\lambda = 300 \text{ \AA}$$

0.1/0.9
 0.1/0.9
 0.1/0.9
 0.1/0.9
 0.1/0.9

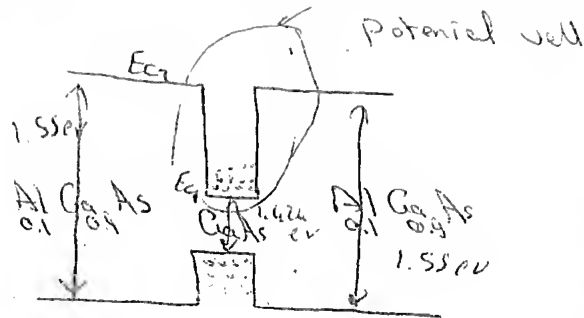
Band Diagram

Date: _____

$$1.424 + 1.247x \quad , \quad x < 0.45$$

$$= 0.1$$

$$1.55 \text{ eV}$$

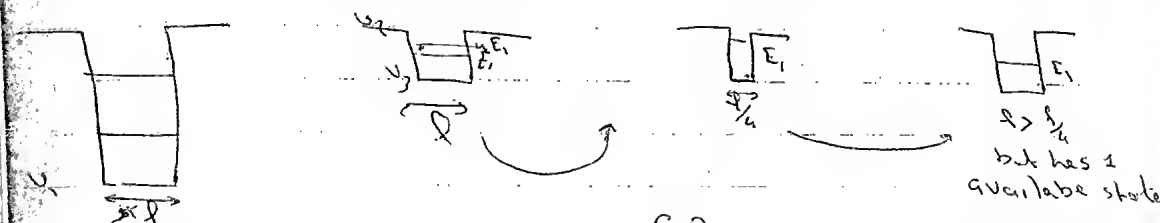


$$= 1.424 \text{ eV}$$

Finite Potential well

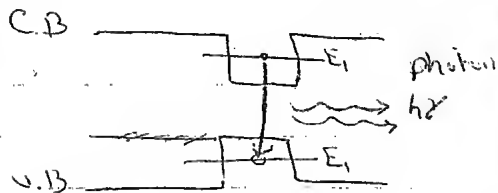
$$E_c > E_n > E_v$$

As the thickness of active material decreases \rightarrow (1) the first state shifts up & distance between successive states increases



1st in every band \rightarrow 1-wave length of photon

app:- Laser Diode



$$E_g = 0.67 E_g \rightarrow E_g - E_{g, \text{GaAs}} = 1.55 - 1.424 = 0.126$$

$$E_v = 0.33 E_g$$

$$E_g = 1.55 - 1.424 = 0.126$$

$$E_{c1} = (0.67 \times 0.126) + 1.55 =$$

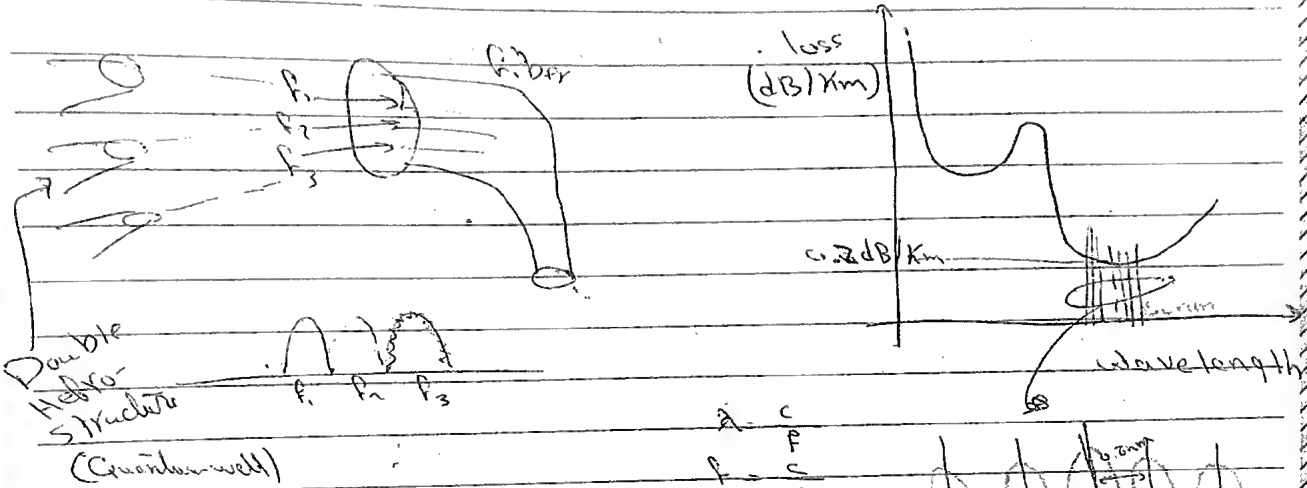
$$E_{v1} = 1.424 - (0.33 \times 0.126) =$$

Subject:

Date:

* Objective of Laser Diode

Dense Wavelength Division Multiplexing



Wavelength of light

optical sources

Wavelength of light

$$\lambda = \frac{c}{f}$$

$$f = \frac{c}{\lambda}$$

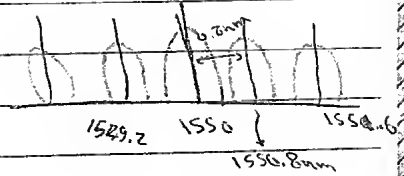
$$\frac{df}{d\lambda} = \frac{c}{\lambda^2}$$

$$df = \frac{c}{\lambda^2} d\lambda$$

$$1550$$

$$0.8$$

$$0.8 \text{ nm} \rightarrow 100 \text{ GHz}$$



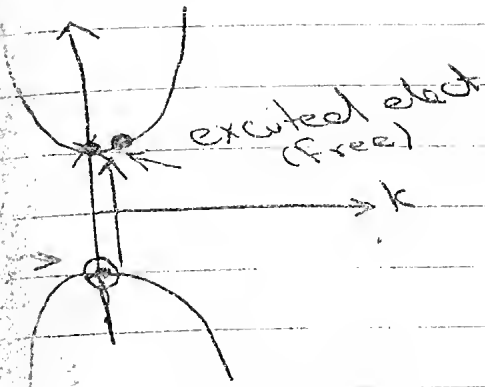
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Interaction of light with matter

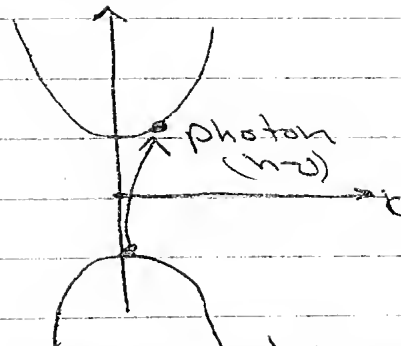
① Absorption



upward transition

excited state

② Spontaneous Emission



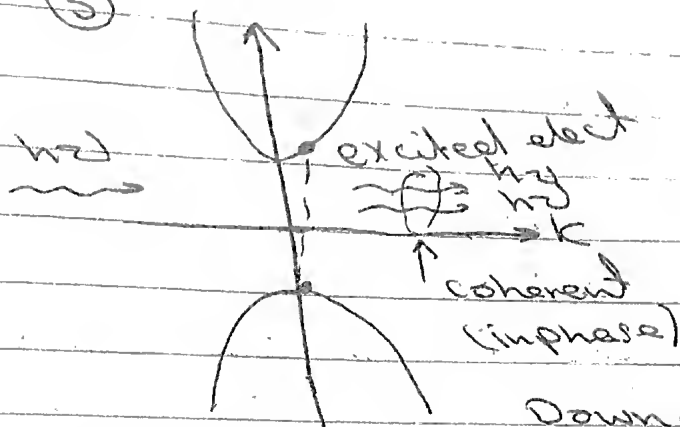
downward trans

APP
LEO



①

③



Downward trans

APP

LO

Transition

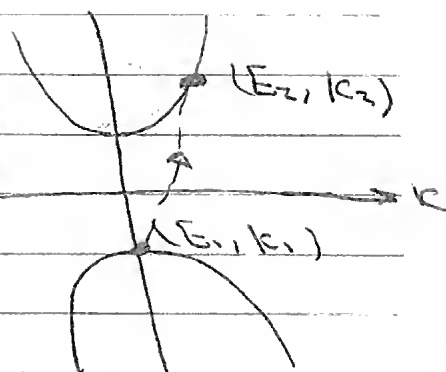
* Conservation of energy

$$E_2 = E_1 + E_p$$

↑ ↑
Final initial
energy energy
of elect of elect

(E_p, k_p)

Photon
~~~~~  
~~~~~



* conservation of momentum

$$p_2 = p_1 + p_p$$

$$\hbar k_2 = \hbar k_1 + \hbar k_p$$

$$k_2 = k_1 + k_p$$

$$E_p = h\nu = \frac{hc}{\lambda}$$

$$\lambda \sim 0.5 \mu m$$

↓
1.5 μm

$$E_g = \frac{1.24}{\lambda_g}$$

↓

$$E_g = 1.24 \text{ eV}$$

is ph absorption

$$1 \text{ eV} < E_g < 3 \text{ eV}$$

sem met

↓
semicond

②

of pho can allow transi
iconed material

$$k_2 = k_1 + k_p$$

\downarrow \downarrow
 vector photon
 wave vector = $\frac{2\pi}{\lambda}$

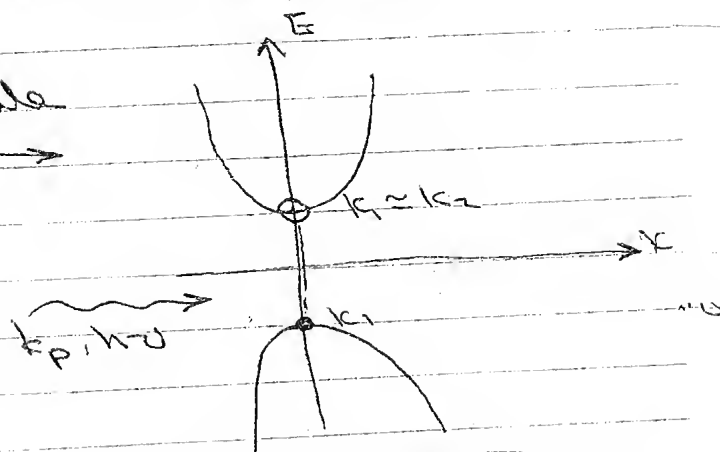
$$\frac{2\pi}{100 \text{ \AA}} = 2\pi \times 10^8 \quad \frac{2\pi}{1 \times 10^6} = 2\pi \times 10^6 \text{ m}^{-1}$$

$$k_2 - k_1 \approx 0$$

momentum of photon is neglected
momentum of electron

selection rule

$$\Delta k = 0 \rightarrow$$



vertical transition

= pho assisted transition

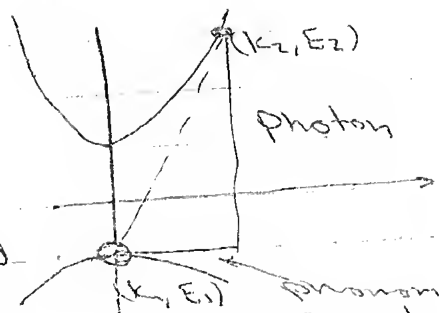
indirect transition

photon, phonon

of lattice

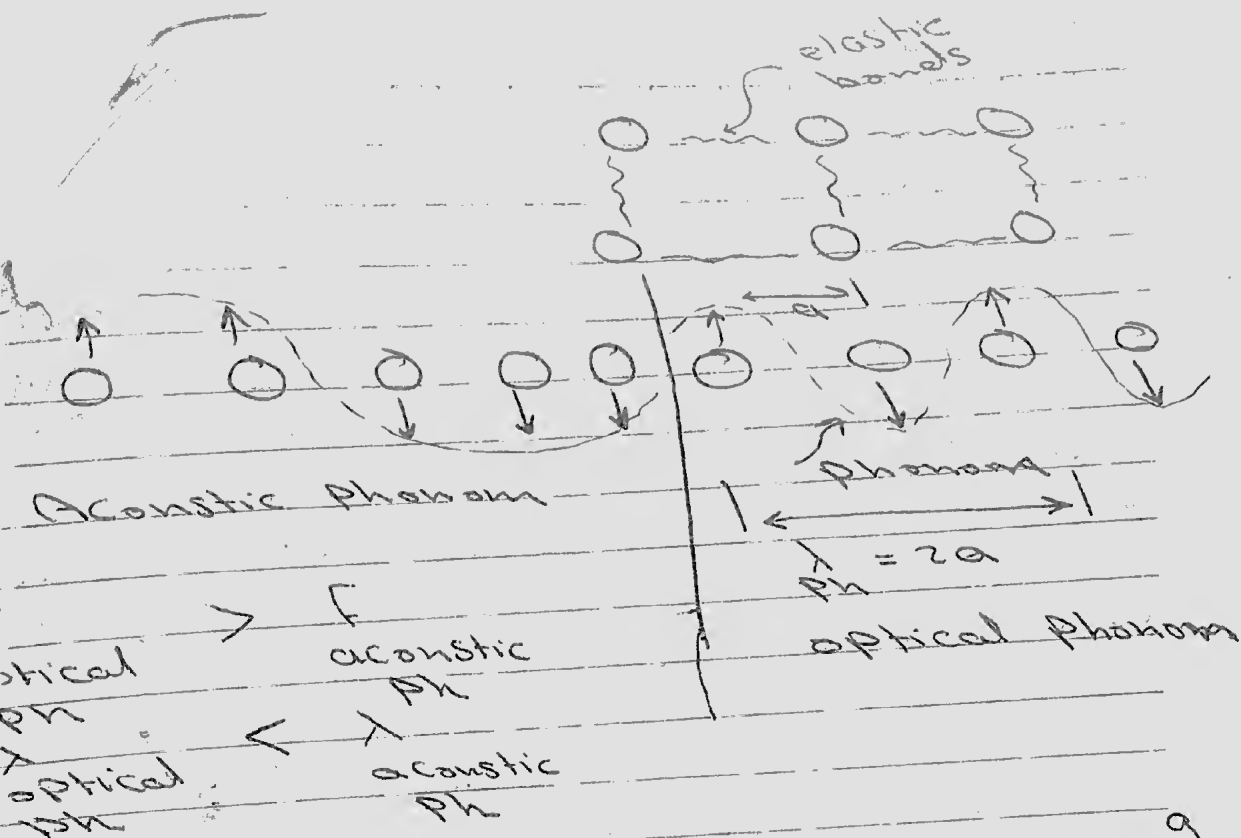
vibration

phonon assisted transi



③

k is conserved



$$k = \frac{2\pi}{\lambda_{\text{optical Ph}}} \quad \text{for ex} = \frac{2\pi}{10 \text{ \AA}} = 2\pi \times 10^9$$

Energy \approx Small \approx 10 meV \rightarrow 70 meV

Phonon \approx Thermal energy

Photon	Phonon
Quantum of light	Quant of lattice vibrat
1 eV \rightarrow 3 eV	10 meV \rightarrow 70 meV
0.5 μm \rightarrow 1.5 μm	10 \AA \rightarrow 100 \AA
high energy	Low energy
no momentum	high momentum

Apply Boltzman App

$$|E - E_F| \gg kT$$

$$P_e = e^{-(E_2 - E_F)/kT} * e^{(E_1 - E_F)/kT}$$

$$= e^{-(E_2 - E_1)/kT}$$

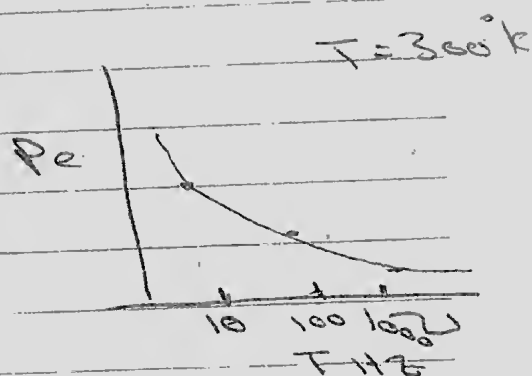
$$= e$$

$$P_e = e^{-h\nu/kT}$$

$$0.025 \text{ meV}$$

$$\nu \uparrow \quad P_e \downarrow$$

$$P_e \approx \text{zero}$$

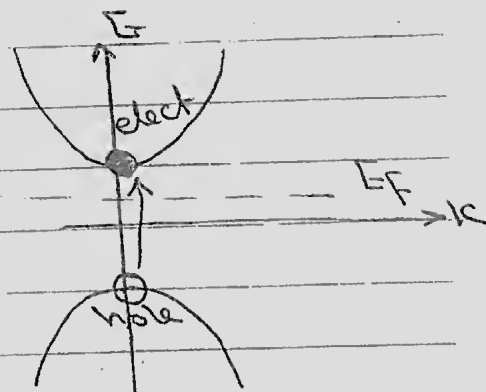


$$* P_{ab} = ??$$

✓ elect (E_1) exists in v.B

✓ vacant state (E_2)

exists in c.B



$$P_{ab} = \frac{1}{e^{(E_1 - E_F)/kT} + 1} \left[\frac{1}{e^{(E_2 - E_F)/kT} + 1} \right]$$

$$= \frac{1}{e^{(E_1 - E_F)/kT} + 1} \left[\frac{e^{(E_1 - E_F)/kT}}{e^{(E_2 - E_F)/kT} + 1} \right]$$

Boltzman Approx

$$|E - E_F| \gg kT$$

$$P_{ab} \approx 1$$

$$P_{ab} > P_e$$

(6)